APPARATUS AND PROCESS FOR FORMING THREE-DIMENSIONAL FIBROUS PANELS

FIELD OF THE INVENTION

The invention relates to the formation of fibrous panels by introducing an aqueous fiber stock into a mold and dewatering and compressing the stock to form a wet panel that is subsequently removed from the mold and dried.

BACKGROUND OF THE INVENTION

Traditionally, it has been common to use wood such as plywood when there is a need for structural panels of relatively low cost. Increasingly, however, efforts have been made to develop low-cost structural panels from molded fibrous material such as wood fibers of the type used in some papermaking processes. In one process, an aqueous fiber stock is vacuum deposited on a porous mold or screen. The stock is partially dewatered and conforms to the shape of the mold to form a wet molded panel. The panel is removed from the mold and dried in a dryer to remove the water. In many cases, only the side of the panel that was against the mold is finished (i.e., smooth); the opposite side, which was not contacted by any mold surface, remains unfinished or rough.

More recently, processes have been developed wherein the panel is pressed between two mold parts so that both sides of the panel are finished. One such process is disclosed in U.S. Patent No. 4,702,870 to Setterholm et al. The process produces a three-dimensional panel that is flat on one side and has a system of intersecting ribs similar to a honeycomb structure projecting from the opposite side. To make the panel, an aqueous fiber stock is deposited into a mold comprising a porous support plate or screen on which are affixed a plurality of resilient elastomeric mold pieces or projections of truncated conical or pyramidal shape. The mold pieces are spaced apart on the porous support plate so that intersecting channels are defined between the mold pieces. The aqueous stock fills the mold to a depth greater than the height of the mold pieces, so the stock covers the upper surfaces of the mold pieces. A flat mold plate is urged against the stock and presses the stock down into the mold; the stock is dewatered through openings in the porous support plate. The pressure on the stock in the urging direction causes

compression and densification of the panel in its thickness direction (i.e., perpendicular to its plane). Moreover, this pressure also causes the elastomeric mold pieces to be compressed to a smaller height, and as a result they grow in width or diameter and thereby exert pressure on the stock in the lateral direction (i.e., parallel to the plane of the panel). Accordingly, the ribs of the panel that are formed in the channels between the mold pieces are compressed both in the thickness direction and the lateral direction. The process thus is able to produce a panel with substantially homogeneous density in all directions, and with substantial bending stiffness relative to its weight.

A drawback of the process of the '870 patent, however, is that the compressible mold pieces are not very durable and tend to break or become detached from the support plate after a relatively small number of molding cycles. Furthermore, the mold pieces tend to become compression-set so that they lose their ability to provide the needed lateral compression of the panel ribs. The compressible mold pieces thus must be replaced periodically, which is time-consuming and expensive.

SUMMARY OF THE INVENTION

The invention addresses the above needs and achieves other advantages, by providing a process and apparatus for making a three-dimensional fibrous panel wherein two or more progressively formed molds are employed. Each mold has a support plate having water drain openings, and a plurality of rigid mold pieces affixed to the support plate. The mold pieces are of truncated conical or pyramidal shape and are spaced apart on the support plate to define channels between them for forming ribs on a panel. In accordance with the invention, a panel is initially formed in a first mold characterized by mold pieces whose draft angle (i.e., the angle between the side surfaces of the mold piece and the vertical or thickness direction of the panel) is relatively large to facilitate removal of the panel from the first mold; the channels between the mold pieces are relatively wide. After pressing in the first mold, the panel is removed and is placed into a second mold generally similar to the first mold but characterized by mold pieces of smaller draft angle and smaller height, and by narrower channels. The panel is pressed in the second mold to re-form and further compress and densify the panel. The ribs are compressed in

the lateral direction because the channels are narrower than the widths of the ribs as formed in the first mold, and are compressed in the thickness or vertical direction because the channels are less deep than the height of the ribs as formed in the first mold. If desired, a third mold that is further progressively shaped can be employed for further compression and densification of the panel.

The rigid mold pieces and the support plates can be made of various materials, including metallic or non-metallic materials. Suitable non-metallic materials can include hard plastic materials, hard rubber or rubber-like materials, fiber-matrix composite materials, ceramic materials, and others. The mold pieces can have water drain passages through them, or can be non-porous.

The rigid mold pieces are substantially more durable than compressible mold pieces, and compression-setting of the mold pieces is not an issue.

The mold pieces of the final mold preferably have relatively small draft angles (e.g., as low as 2 degrees, although they can be as high as 30 degrees). Small draft angles translate into ribs with side walls that are close to perpendicular to the flat face of the panel.

The panel can be at least partially dried while still in the second mold. In one embodiment, the second mold is non-metallic, and the panel is microwave dried while still in the second mold.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 is a top view of a first mold member in accordance with one embodiment of the invention;

FIG. 2 is a cross-sectional view taken on line 2-2 in FIG. 1;

FIG. 3 is a top view of a second mold member;

FIG. 4 is a cross-sectional view taken on line 4-4 in FIG. 3;

FIG. 5 is a cross-sectional view taken through a single mold piece of the first mold;

FIG. 6 is a view similar to FIG. 5, showing an alternative embodiment of a mold member in accordance with the invention;

FIG. 7 is a perspective view of yet another embodiment of a mold member in accordance with the invention;

FIG. 8A illustrates a first step in a process for making a fibrous panel in accordance with one embodiment of the invention, wherein an aqueous fiber stock is deposited into a first mold member;

FIG. 8B shows the stock being compressed in the first mold member to form a wet panel;

FIG. 8C shows the wet panel being removed from the first mold member;

FIG. 8D depicts the wet panel being inserted into a second mold member;

FIG. 8E illustrates the panel being compressed in the second mold member;

FIG. 8F shows the panel after removal from the second mold member; and

FIG. 9 is a perspective view of the finished panel.

DETAILED DESCRIPTION OF THE INVENTION

The present inventions now will be described more fully hereinafter with reference to the accompanying drawings, in which some but not all embodiments of the invention are shown. Indeed, these inventions may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these

embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

FIGS. 1, 2, and 5 depict a first mold member **20** of an apparatus for molding fibrous panels in accordance with one embodiment of the invention. The first mold member **20** comprises a support plate **22** that is porous so that water can drain through the plate. The plate **22** can be formed of various metallic or non-metallic materials, including but not limited to cast iron, steel, aluminum, and other metals, hard plastic materials, hard rubber or rubber-like materials, fiber-matrix composite materials, ceramic materials, and others. The porous support plate **22** can have various structures. For example, the plate can comprise a plate (which can be rigid) having holes extending through its thickness. Alternatively, the plate can comprise a screen or the like. As another example, the support plate can be comprised of more than one separate element each of which is porous or has drain holes through it; for instance, the support plate can comprise a lower plate (which can be rigid) having relatively large drain holes, and a screen having relatively smaller openings overlying the plate. An advantage of this arrangement is that the screen can have very small openings (which would be difficult to form through the plate) and can impart a substantially smooth finish to the flat side of a panel; additionally, the screen potentially can be made to be separable from the underlying plate to facilitate cleaning the screen as needed. The plate **22** alternatively can be formed of a porous metal, or a non-metal such as foamed plastic or ceramic.

The first mold member **20** also includes a plurality of rigid mold pieces **24** affixed to the upper surface of the plate **22**. The mold pieces **24** are generally shaped as truncated 3D tapered structures (e.g., truncated conical or pyramidal structures), each having a generally flat upper surface **26** that is substantially parallel to the upper surface of the support plate **22**, and one or more side surfaces **28** (i.e., a truncated cone would have one side surface formed as a surface of revolution, whereas a truncated pyramid would have a plurality of side surfaces angularly oriented with respect to one another as in FIG. 1) that extend from the upper surface **26** down to the top of the support plate **22**. The side surfaces **28** preferably are substantially linear in vertical cross-section (as shown in FIGS. 2 and 5), although a small degree of concavity or convexity could be present.

The side surfaces **28** form a nonzero draft angle α (FIG. 2) with respect to the vertical direction (i.e., the direction perpendicular to the support plate **22**). The draft angle α preferably is sufficient in magnitude to allow the panel formed in the first mold member to be readily removed from the mold member; the large the draft angle, in general, the easier it is to remove the panel.

The mold pieces **24** can be formed of various metallic or non-metallic materials, including but not limited to cast iron, steel, aluminum, and other metals, hard plastic materials, hard rubber or rubber-like materials, fiber-matrix composite materials, ceramic materials, and others. The mold pieces, as noted, are rigid, i.e., substantially incompressible, so that under the levels of pressure exerted on them during a molding operation they do not undergo any substantial deformation. The mold pieces can be formed separately from and then affixed to the support plate **22** by various techniques, including but not limited to welding, affixing with adhesive, attaching with fasteners, or other techniques; alternatively, the mold pieces can be integrally formed with the support plate, such as by molding or casting, or by machining the plate and mold pieces from a single piece of material. The aforementioned techniques are given by way of example, and not by way of limitation; other techniques can be used. The mold pieces can include water drain passages **30** extending therethrough generally in the height direction of the mold pieces. The passages **30** communicate with drain openings in the support plate **22** so that water can drain through the passages **30** and then through the support plate, as further described below. Alternatively, the mold pieces can be non-porous so that all water draining occurs through the support plate.

The mold pieces **24** are arranged on the support plate **22** in an array, such as a column, row arrangement as shown in FIG. 1. The arrangement of mold pieces may also be specific to a need for a varying lattice or grid design. As a result of the arrangement of mold pieces, there are spaces or channels **32** between the mold pieces **24** that form an intersecting grid or lattice. These channels will form the ribs on a fibrous molded panel, as described below.

The apparatus for molding fibrous panels also includes at least one additional mold member, such as the mold member **40** shown in FIGS. 3 and 4. The mold member **40** is progressively formed with respect to the first mold member **20**, as further described below. The mold member **40** includes a porous support plate **42**, which can be constructed in generally the same manner as previously described for the support plate **22** of the first mold member. Attached to the support plate **42** are a plurality of mold pieces **44** of truncated conical or pyramidal configuration. The mold pieces **44** can be constructed in generally the same manner as previously described for the mold pieces of the first mold member. In particular, the mold pieces **44** are rigid, within the meaning previously set forth. The mold pieces have upper surfaces **46** that are generally planar and generally parallel to the support plate, and side surfaces **48** that extend from the upper surfaces **46** down to the support plate. The mold pieces **44** can include drain passages **50**. The side surfaces **48** form a nonzero draft angle β with respect to the vertical. Suitably, the draft angle β can be from about 2° to about 30°, more preferably about 2° to about 20°. The side surfaces **48** can be linear in vertical cross-section (i.e., in a plane that is normal to the support plate **42**).

The mold pieces **44** are arranged on the support plate **42** in an array, such as a column, row arrangement as shown in FIG. 3. The arrangement of mold pieces **44** generally would be substantially the same as or similar to the arrangement of mold pieces **24** in the previous mold, but the mold pieces **44** could be sized and/or spaced differently from the mold pieces **24**. As a result of the arrangement of the mold pieces **44**, there are spaces or channels **52** between the mold pieces **44** that form an intersecting grid or lattice. These channels will form the ribs on a fibrous molded panel, as described below. The mold pieces **44** are located, on center, substantially identically with the mold pieces **24** of the first mold member, so that the ribs on a panel formed in the first mold member will align with and fit into the channels **52** of the second mold member.

With respect to the progressive formation of the two mold members **20, 40**, there are three significant geometrical properties of the second mold member **40**, one or more of which differ from those of the first mold member **20**: (1) the draft angle of the mold pieces; (2) the widths of the channels between the mold pieces; and (3) the height of the

mold pieces. More particularly, the draft angle α of the first mold pieces **24** preferably is larger than the draft angle β of the second mold pieces **44**. Preferably, the first draft angle α is at least about 3° greater than the second draft angle β. This is another way of saying that the side surfaces of the mold pieces **44** are more upright (i.e., closer to perpendicular to the support plate) than those of the mold pieces **24**, and hence the sides of the ribs formed in the second mold member **40** will be more upright than those of the ribs formed in the first mold member **20**.

The widths of the channels **52** in the second mold member preferably are smaller than the widths of the channels **32** in the first mold member. Thus, the ribs formed in the second mold member will be thinner than those formed in the first mold member.

Finally, the height of the mold pieces **44** preferably is smaller than the height of the mold pieces **24**. Therefore, the height of the ribs formed in the second mold member will be smaller than the height of the ribs formed in the first mold member.

The progressive configurations of the mold members **20, 40** are provided so that a panel formed and compacted in the first mold member can be further compacted and densified in the second mold member. This is illustrated in FIGS. 8A through 8E, which depict a series of process steps involved in molding a panel in accordance with the invention. In a first step, the first mold member **20** is positioned in a horizontal orientation and is filled with a fluid slurry or stock **60** containing fibers, and optionally containing other components such as fillers, additives, etc. The initial stock **60** generally will have a relatively low dry fiber content by weight, for example about 1% to about 10%. The mold member is filled to a depth exceeding the height of the mold pieces **24**, as shown. To prevent the stock from flowing out the sides of the mold member, the mold member can be surrounded by a wall (not shown) that extends about the perimeter of the mold member.

Next, as shown in FIG. 8B, a mold plate **70** having a substantially planar lower surface is pressed downward onto the stock and is urged toward the support plate **22** of the mold member. As a result, water from the stock **60** is forced through the porous support plate **22**; the openings in the plate are sized to substantially prevent fibers in the

stock from passing through. In the case where the mold pieces **24** also have water drain passages, water also is forced through those passages. Additionally, the mold plate **70** can also include water drain passages, if desired. Accordingly, the stock **60** is dewatered to some extent. The pressure exerted by the mold plate **70** that is suitable for achieving a desired degree of dewatering depends on a number of factors. The pressure exerted by the mold plate **70** can be about 100 to 150 psi.

FIG. 8C illustrates that the next step in the process is to remove the panel **80** from the first mold member **20**. The relatively large draft angle α of the mold pieces **24** facilitates removal of the panel, which at this point is semi-dry. It will be noted that the sides of the ribs **82** on the panel are inclined to a substantial extent relative to the planar face of the panel, which reflects the relatively large draft angle α.

The semi-dry panel is then placed into the second mold member **40** as depicted in FIG. 8D. The ribs **82** on the panel align with the channels **52** in the mold member. However, because the channels **52** are narrower and shallower than the ribs **82** (by virtue of the greater width and smaller height of the mold members **44** relative to the mold members **24**), it is evident that further densification of the panel will occur upon pressing.

FIG. 8E shows the panel **80** being pressed by the mold plate **70**. The panel is compressed into a total volume that is smaller than the starting volume of the panel, because the channels are narrower and shallower than the ribs. Thus, the panel is further densified as additional water is expressed through the porous support plate **42** (and, if present, the drain passages in the mold pieces **44**). It is important to note that because of the progressive formation of the mold members **20, 40**, the panel's ribs **82** are compressed and densified not only in the vertical direction along which the mold plate **70** is urged, but also in the lateral direction (left-to-right in FIG. 8E). This lends substantial strength and stiffness to a finished panel because the panel has substantially uniform density in all directions.

The second pressing in the mold **40** suitably can be carried out at a pressure of about 50 to 200 psi. The panel at this point typically will have a density of about 10 to 20 lb/ft^3.

To create the finished panel, the panel must be dried to evaporate substantially all of the remaining water. The drying suitably is performed by thermal drying techniques. For instance, the panel **80** can be removed from the mold member **40** (see FIG. 8F) and placed into a drying device such as an oven or microwave dryer for a sufficient period of time for the panel to reach the desired dryness. Alternatively, the panel can be dried while still in the mold member **40**. In the case of microwave drying, this requires that the mold member **40** be constructed of non-metallic materials. For instance, the mold member can be constructed of ceramic.

FIG. 9 shows a finished panel **80** having ribs **82** that are substantially parallel-sided (i.e., having the opposite side surfaces of the ribs parallel to each other, and thus perpendicular to the planar face **84** of the panel).

A ceramic first mold member **20'** is shown in FIG. 6. It will be noted that this mold member does not include water drain passages through the mold pieces **24'**. The mold pieces also are formed integrally with the porous support plate **22'**. The support plate **22'** has water drain passages **23'** extending therethrough.

FIG. 7 shows yet another possible construction for a first mold member **20"**. The mold member is an integral one-piece metal construction (which might be formed, for example, by casting or machining). The mold pieces **24"** are hollow rather than solid, and do not include drain passages. The support plate **22"** has water drain passages **23"** therethrough.

Various other materials and construction methods can be used for making the mold members of the apparatus, as previously noted. The important factor is that the mold members be progressively configured as described. By progressively forming the mold members, the mold members can be rigid, as opposed to the requirement of using elastomeric mold pieces as in the prior art. By progressively reducing the draft angle from one mold member to the next, the ribs of a panel are progressively formed to be closer and closer to parallel-sided. Additionally, the reduction in height and increase in width of the mold pieces from one mold member to the next result in progressive densification of the ribs in the vertical or height direction as well as in the lateral or width

direction. Although only two mold members have been illustrated and described, the invention can employ more than two progressively formed mold members if desired.

The ribs **82** shown in FIG. 9 form a simple orthogonal grid, but it will be recognized that various other rib configurations can be used in accordance with the invention by suitably configuring the mold pieces of the mold members. Among the advantages of the invention is that because the mold members are rigid and thus do not deform appreciably during the pressing, the configuration of the ribs of the panel can be precisely controlled by precisely controlling the configuration of the last mold member that produces that final panel form. In contrast, with prior panel-forming methods and apparatus employing rubber mold pieces that substantially deform during pressing, the panel configuration is dependent on the deformed shape of the mold pieces, which may be difficult to accurately predict or control. Additionally, with deformable mold pieces, it is difficult to provide mold pieces of complex shapes, but the rigid molds in accordance with the invention can be shaped in virtually any desired configurations, as long as the mold pieces have a sufficient draft angle to allow the panel to be removed from the molds.

Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.